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Project Title: Critical Shear Stress and Erosion of Cohesive Sediments

Project Category: Contaminated Sediments

Rank by Organization (if applicable): 0

Total Funding Requested ($): 177,791 **Project Duration:** 2 Years

Abstract:

Contaminated sediments have been identified as the major source of continued water quality impairment at all 43 Areas of Concern (AOCs) in the Great Lakes basin, and modeling has been used extensively to evaluate different remediation alternatives. In this project a model for erosion of cohesive sediment beds will be tested and applied to evaluate its utility in sediment transport modeling for several of these AOCs. A new theoretical model has been developed to predict critical shear stress and erosion rates on the basis of a single parameter that is evaluated from field measurements of bulk density and size distribution only. Laboratory experiments are planned to test the theory using several artificial sediments, as well as natural sediment samples taken from several Great Lakes AOCs, including for example the Buffalo River, Fox River, St. Louis River, Oswego River, St. Clair River, Ashtabula River and Detroit River (other sites may be chosen depending on site assessment needs). The purpose of the proposed research is to better predict erosion rates for the cohesive beds characteristic of these Great Lakes sites, in order to improve model results by reducing uncertainty associated with the rates at which contaminants might be reintroduced into the water column as a result of flow-driven resuspension. It is expected that results of this research will be useful for virtually all sediment transport modeling efforts in the Great Lakes basin.

Geographic Areas Affected by the Project

States:

- [x] Illinois
- [ ] Indiana
- [x] Michigan
- [x] Minnesota
- [x] New York
- [ ] Pennsylvania
- [x] Wisconsin
- [x] Ohio

Lakes:

- [ ] Superior
- [ ] Huron
- [ ] Michigan
- [ ] Erie
- [ ] Ontario
- [x] All Lakes

Geographic Initiatives:

- [ ] Greater Chicago
- [ ] NE Ohio
- [ ] NW Indiana
- [ ] SE Michigan
- [ ] Lake St. Clair

Primary Affected Area of Concern: All AOCs

Other Affected Areas of Concern:

For Habitat Projects Only:

Primary Affected Biodiversity Investment Area:

Other Affected Biodiversity Investment Areas:

Problem Statement:

Sediment and associated hydrophobic contaminant transport modeling has been used extensively to evaluate possible effects of different remediation alternatives at several of the Great Lakes Areas of Concern (AOCs), including the Fox River in Wisconsin, the Buffalo River in New York, the Saginaw River in Michigan and others. A critical feature of sediment transport models is specification of the bottom boundary condition, which incorporates erosion and settling fluxes. Unfortunately, theoretical descriptions of resuspension of cohesive sediments have largely failed to be generally representative, or transferable from one site to another, and most studies have relied on site-specific, empirical measurements of erosion rates. The usual procedure in obtaining these measurements involves taking samples from the site under study and directly measuring erosion rates as a function of applied shear stress in a laboratory flume (Lick, McNeil and others). The critical parameters required for modeling are the shear stress at which erosion just starts (the critical shear stress, tc) and the rate of erosion that occurs once tc is exceeded. The model most commonly used in Great Lakes applications was originally reported by Gailani and Lick (1991), and involves determination of three constants, in addition to time of deposition and critical shear stress. The values for each of these parameters are site specific and must be determined empirically.

For the present proposal a new sediment erosion model is developed to estimate both tc and the erosion rate, E. The model shows that these parameters may be evaluated on the basis of measurements of sediment bulk density and size distribution alone, thus greatly simplifying data collection and evaluation needs to calculate resuspension at a given site. The model has been applied to several data sets reported in the literature (Torfs, 1994; Panagiotopoulos, 1997), with excellent results, though further experiments are needed to consider a wider range of parameters, specifically characteristic of sediment beds in the Great Lakes basin. This will be accomplished by conducting laboratory experiments with several well-defined, but artificial sediments, as well as with sediment samples taken from several of the Great Lakes tributaries, mentioned above.

Proposed Work Outcome:

Proposed Work: A new model for erosion of cohesive sediment beds has been developed which takes into account the effects of mixtures of cohesive and non-cohesive particles, as a function largely of sediment size distribution. Briefly, this is done by combining the normal Shields' parameter for non-cohesive particles with an additional shear parameter defined to account for cohesive forces, in order to evaluate the critical shear stress for erosion. The erosion model is an extension of Krone's (1962) relation and incorporates directly the two shear parameters. The model is based on a force balance applied to particles on the bed and accounts for fluid drag and lift, as well as particle submerged weight and interparticle cohesive forces. All parameters that depend on the properties of the finer-grained materials in the sediment and the basic properties of the solution (i.e., density, viscosity) are combined into a single parameter, called the cohesive shear coefficient, which can be determined from measurements of sediment size distribution and bulk density. Combined with existing models for evaluating other forces in the overall force balance, such as fluid drag and lift, a final expression for tc as a function of the shear coefficient is obtained.

The model calculations agree very closely with the data sets noted above. In particular, the model reproduces the expected trend in values for tc with differing clay content. That is, tc is relatively low for small clay content and increases slowly as clay content increases. At a clay content of around 5 - 15% (by weight), there is a transition between mostly non-cohesive and cohesive erosion behavior, with a sharper increase in tc with further increases in clay content, reaching a peak when clay content is around 40 - 50%. For further increases in clay content tc decreases again as the material becomes more porous.

To carry out the objectives of this research it is necessary to further test the model, specifically under a wider range of conditions (higher clay content, different mineral composition, etc.) than can be found in the literature. This will be done using a laboratory flume in which shear stress can be carefully controlled and tc and E can be accurately measured. The laboratory apparatus will be similar in design to Lick's flume, using a piston arrangement to maintain a level bed section as erosion proceeds. An existing recirculating water tunnel at the University at Buffalo is available for these tests, though it will require modifications to introduce the sediment bed test section. Experiments will first be conducted using artificial sediment mixtures, in order to further test the model under well-known and controlled conditions. However, the main experiments will be conducted for field samples taken from several Great Lakes sites mentioned above. All samples, for both artificial and field sediments will be analyzed for bulk density, sediment size distribution, organic contents, and mineral composition. Flume tests will then be carried out to measure tc and E as functions of excess shear stress (greater than tc). Most of the required experimental equipment is already available in the Environmental Fluid Mechanics Laboratory at the University at Buffalo, though several modifications will be required, as well as additional instrumentation and supplies for obtaining field samples. The model will be fit primarily by evaluating the cohesive shear parameter and other erosion parameters for a range of artificial and actual sediments.

Project Outcome: The main outcome of this research will be a demonstration of the applicability of a new model that can be used to estimate critical shear stress and erosion rates for sediment beds characteristic of Great Lakes AOCs. The model has much simpler data requirements than previous approaches and should be directly applicable in virtually all sediment transport modeling efforts for the AOCs. Our experimental results and the developed resuspension sub-model will contribute directly to ongoing assessments in many AOCs throughout the basin. A major contribution of the model is to greatly reduce the uncertainty of sediment erosion predictions, by providing a theoretically-based calculation of critical shear stress and erosion rate, thereby reducing a dependence on empirical measurements. This is helpful for general water quality evaluations and, in particular, in the evaluation of the effects of different remediation alternatives. In addition, further bed sediment characteristics for several of the AOCs will be measured and reported.

Project Milestones:	**Dates:**
Project Start	09/2000
complete model theoretical testing	11/2000
test model application to lit. data	01/2001
construct and test exp. apparatus	01/2001
complete tests with artificial sediments	07/2001
collection and testing of field samples	01/2002
complete experiments, system-level model	06/2002
Project End	08/2002

☐ Project Addresses Environmental Justice

If So, Description of How:

☒ Project Addresses Education/Outreach

If So, Description of How:

We will contribute to on-going site assessments in those AOCs from which we collect sediments by reporting the results of our erosion studies in those areas.

Project Budget:

	Federal Share Requested ($)	**Applicant's Share ($)**
Personnel:	55,856	7,714
Fringe:	6,859	2,257
Travel:	3,500	0
Equipment:	0	0
Supplies:	6,000	0
Contracts:	50,000	0
Construction:	0	0
Other:	2,000	0
Total Direct Costs:	124,215	9,971
Indirect Costs:	53,576	5,384
Total:	177,791	15,355
Projected Income:	0	0

Funding by Other Organizations (Names, Amounts, Description of Commitments):

n/a

Description of Collaboration/Community Based Support:

We will collaborate with agencies responsible for each of the AOCs from which we obtain samples for analysis and testing with our erosion model.